MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2015/2016

ENT3076 – NANOSCIENCE
(NANO)

08 MARCH 2016
2:30 p.m. - 4:30 p.m.
(2 Hours)

INSTRUCTION TO STUDENTS

1. This Question paper consists of 5 pages including cover page with **FOUR** Questions only.

2. Attempt all **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

List of Constants

Electron mass in free space, $m_o = 9.11 \times 10^{-31}$ kg
One electron volt, (1eV) = 1.60×10^{-19} J
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Reduced Planck's constant, $\hbar = 1.05 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K
Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-14}$ Fcm^{-1}

List of Formulas

$$n = 1 + \sqrt{\frac{2m^* V_b L^2}{\pi^2 \hbar^2}}$$

$$\varepsilon_n = \frac{\hbar^2 \pi^2}{2m^* L^2} n^2$$

$$\frac{\rho}{L} = \frac{1}{\pi} \sqrt{\frac{2m^*}{\hbar^2}} \sum_{n1,n2} \frac{1}{\sqrt{E - \varepsilon_{n1,n2}}} \Theta\left(E - \varepsilon_{n1,n2}\right)$$

$$\frac{\rho}{S} = \frac{m^*}{\pi \hbar^2} \sum \Theta\left(E - \varepsilon_n\right)$$

$$N_t = \frac{2\sqrt{2} m^{*\frac{3}{2}}}{3\pi^2 \hbar^3} \left|V_b\right|^{\frac{3}{2}} L_x L_y L_z$$

Question 1

(a) Categorize following junctions that formed by Silicon (Si), Germanium (Ge), Gallium Arsenide (GaAs) and Aluminium Gallium Arsenide (AlGaAs) into either homojunction or heterojunction.

Si/Ge p-Si/n-Si/p-Si p-AlGaAs/p-GaAs p-GaAs/n-GaAs

Explain why you categorize those junctions into homojunction and heterojunction. [4 marks]

(b) As a material engineer, you fabricated a quantum wire with dimension of L_x=1μm and L_y=40nm and L_z=42nm using Aluminium Nitride (AlN) / Gallium Nitride (GaN) heterostructure. Electron effective mass, electron affinity and energy bandgap of AlN and GaN are listed in Table Q1(b).

Table Q1(b)

Material	Electron Effective Mass	Electron Affinity	Energy Bandgap
AlN	$0.4m_o$	0.6eV	6.2eV
GaN	$0.13m_o$	4.1eV	3.2eV

(i) Calculate the quantized energy ε_{n_1,n_2} of the transverse motion of the electrons at energy level

$$(n_1, n_2) = (1,1), (1,2), (1,3), (2,1), (2,2)$$

where n_1 and n_2 are quantum number for energy confinement at y- and z-directions. [8 marks]

(ii) Calculate the density of states per unit length of the fabricated quantum wire if the total energy of electron gas is 0.01eV. [5 marks]

(iii) Sketch the graph of density of states versus energy for electrons in the fabricated quantum wire and label clearly $\varepsilon_{1,1}$, $\varepsilon_{1,2}$, $\varepsilon_{1,3}$, $\varepsilon_{2,1}$ and $\varepsilon_{2,2}$. Explain the difference between energy at $\varepsilon_{1,2}$ and $\varepsilon_{2,1}$. [5 marks]

(c) Figure Q1(c) shows the optical spectra of a semiconductor near the fundamental edge.

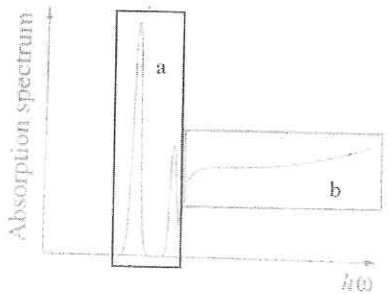

Figure Q1(c)

Identify the area of optical spectra which is caused by excitons and give the definition of excitons. [3 marks]

Continued ...

Question 2

(a) Refer to the electron affinity and energy bandgap of AlN and GaN that listed in Table Q1(b),

(i) Calculate the $|\Delta E_c|$ and $|\Delta E_v|$ for AlN/GaN quantum wire; then [2 marks]

(ii) Sketch the energy band diagram for AlN/GaN quantum wire and label the electron affinity, energy bandgap, $|\Delta E_c|$ and $|\Delta E_v|$ in the diagram. [6 marks]

(iii) Identify AlN/GaN heterostructure is either Type-I (straddling), Type-II (staggered) or Type-III (broken gap). Justify your answer. [3 marks]

(b) Figure Q2(b) shows the Brillouin zone of the face-centre-cubic.

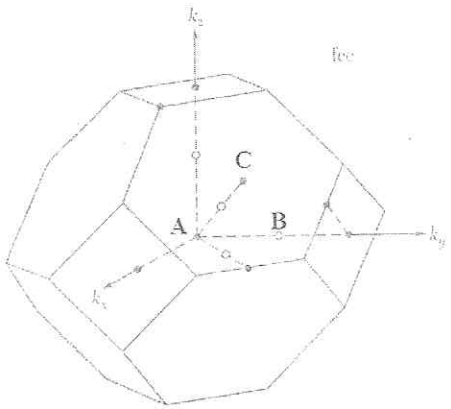

Figure Q2(b)

Table Q2(b)

Symmetric Point	Number of Points	Degeneracy
Γ		
	8	4
Δ		

(i) Identify the symmetric points labelled with A, B, and C, as well as complete Table Q2(b). [4 marks]

(ii) Explain why a symmetric point has 8 for its number of points but only 4 for its degeneracy. [2 marks]

(c) Define phonon scattering that occurs in semiconductor. With the aid of diagrams, explain the acoustic mode and optical mode phonon scatterings in semiconductors. [8 marks]

Question 3

(a) With the aid of diagrams, compare the TWO types of electron transport in quantum wells. [6 marks]

Continued ...

(b) Figure Q3(b) shows the electron drift velocity in GaAs at different applied electric fields. The electron drift velocity in GaAs is higher at 10kV/cm compare to 5kV/cm for $<1\times10^{-12}$s, but the electron drift velocity in GaAs is higher at 5kV/cm compare to 10kV/cm for $>1\times10^{-12}$s.

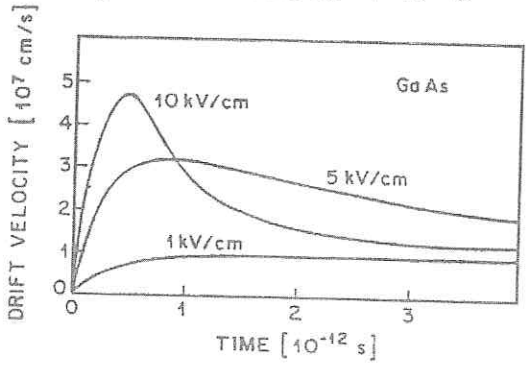

Figure Q3(b)

(i) Name the effect that causing the mentioned phenomenon. [1 mark]

(ii) Explain the mechanism of this effect. [5 marks]

(iii) Briefly discuss how this effect can increase the active region transit time of electrons in high-speed devices. [4 marks]

(c) With the aid of diagrams, discuss the effects of applied voltage on the energy band for a double barrier resonant tunneling structure. [9 marks]

Question 4

(a) Explain the electron transport, velocity and distribution in a Ballistic-Injection device. [8 marks]

(b) (i) As an optoelectronics engineer, you fabricated an AlGaAs/GaAs light emitting diode that emits light at wavelength of ~662nm. Given that

Energy bandgap of GaAs, $E_{g(GaAs)}$	: 1.42eV
First subband in conduction band of GaAs, $\varepsilon_{c,1}$	: 24.8meV
First subband in valance band of GaAs, $\varepsilon_{v,1}$	: 3.7meV

According to phototransition selection rules, determine the transition of electrons are from which subband in conduction band to which subband in valence band. [7 marks]

(ii) Describe phototransition selection rules and write down the related equations. [2 marks]

(iii) Briefly explain the quantum-confined Stark effect in a quantum well structure with the aid of diagrams. [8 marks]

End of paper.